# (12) UK Patent Application (19) GB (11) 2 330 660 (13) A

(43) Date of A Publication 28.04.1999

(21) Application No 9822944.6

(22) Date of Filing 20.10.1998

(30) Priority Data
(31) 09289379 (32) 22.10.1997 (33) JP
(31) 09289380 (32) 22.10.1997
(31) 09289381 (32) 22.10.1997

(71) Applicant(s)
**Japan National Oil Corporation**
**(Incorporated in Japan)**
**2-2 Uchisaiwaicho 2-chome, Chiyoda-ku, Tokyo, Japan**

**Yokogawa Electric Corporation**
**(Incorporated in Japan)**
**9-32 Nakacho 2-chome, Musashino-shi, Tokyo, Japan**

**NKK Corporation**
**(Incorporated in Japan)**
**1-2,Marunouchi 1-chome, Chiyoda-ku, Tokyo 100, Japan**

(51) INT CL[6]
G01F 1/74 1/712

(52) UK CL (Edition Q )
G1N NCVT N19B2B N19F1A N19F7B
G1A AA3 AA4 ABAA AG17 AR2 AT2 AT20

(56) Documents Cited
GB 2219396 A GB 2106645 A EP 0510774 A2
WO 93/24811 A1

(58) Field of Search
UK CL (Edition P ) G1A ABAA ABAG , G1N NCVT
INT CL[6] G01F
Online: WPI

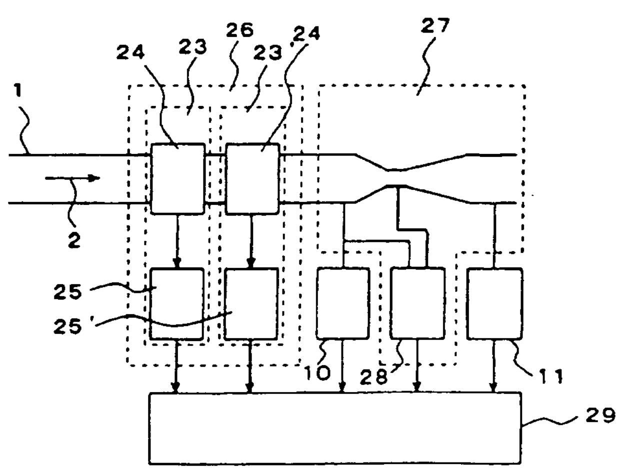
(71) cont
**Japan Petroleum Exploration Co Ltd**
**(Incorporated in Japan)**
**2-20 Higashi-Shinagawa 2-chome, Shinagawa-ku, Tokyo, Japan**

(71), (72) and (74) continued overleaf

(54) Abstract Title
**Measuring flow rates of constituents of a multiphase fluid**

(57) A multiphase flowmeter comprises two spaced sensors 23, 23' which together form a cross-correlation flowmeter 26 for giving a measure of the speed of a multiphase flow passing through a conduit 1. Each sensor measures a parameter of the flow such as dielectric constant or density and measurements are taken from one of the sensors at a time when that sensor is filled with liquid alone (e.g. when the dielectric constant or density reaches a maximum value) and a time averaged sensor output is also determined. From these measurements and the known dielectric constants or densities of the flow components, the proportion of each component is determined, allowing the flow rate of each component to be calculated from the measured speed of the flow. Provision of a differential pressure sensor 27 allows the measurements to be compensated for velocity slip between the gas and liquid phases.

F I G. 4




GB 2 330 660 A

(71) cont

Teikoku Oil Co Ltd
(Incorporated in Japan)
31-10 Hatagaya 1-chome, Shibuya-ku, Tokyo, Japan

(72) Inventor(s)

Tomomi Nishi
Shuichi Haruyama
Yoshiaki Tanaka
Manabu Fueki
Daisuke Yamazaki

(74) Agent and/or Address for Service

Kilburn & Strode
20 Red Lion Street, LONDON, WC1R 4PJ,
United Kingdom

FIG. 1

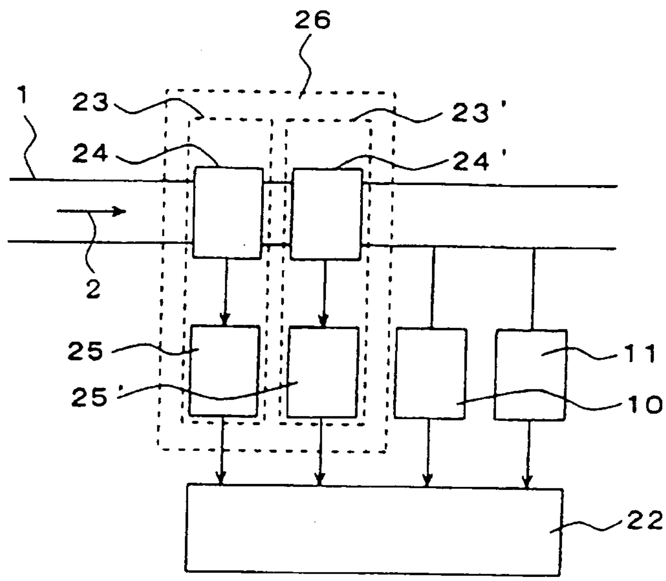



FIG. 2

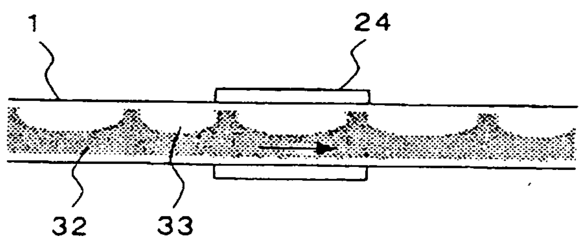



FIG. 3

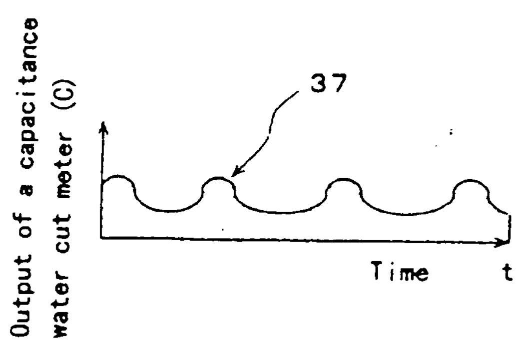


FIG. 4

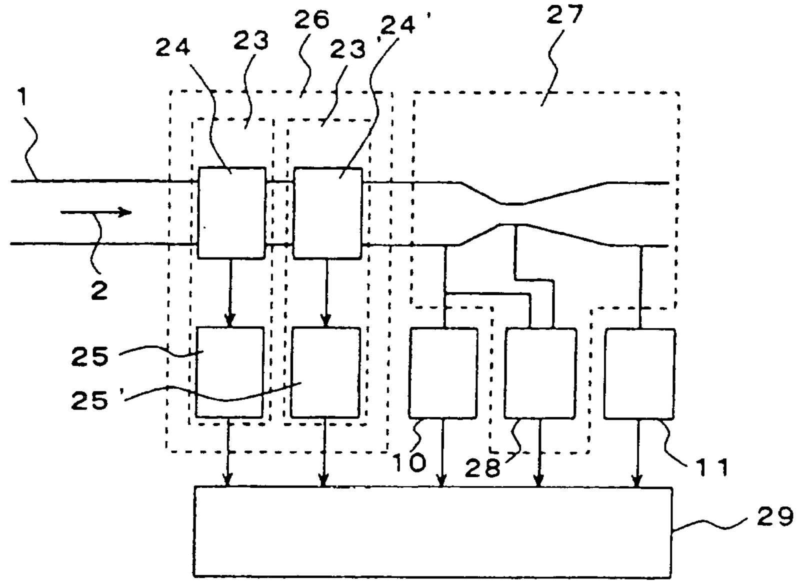



FIG. 5

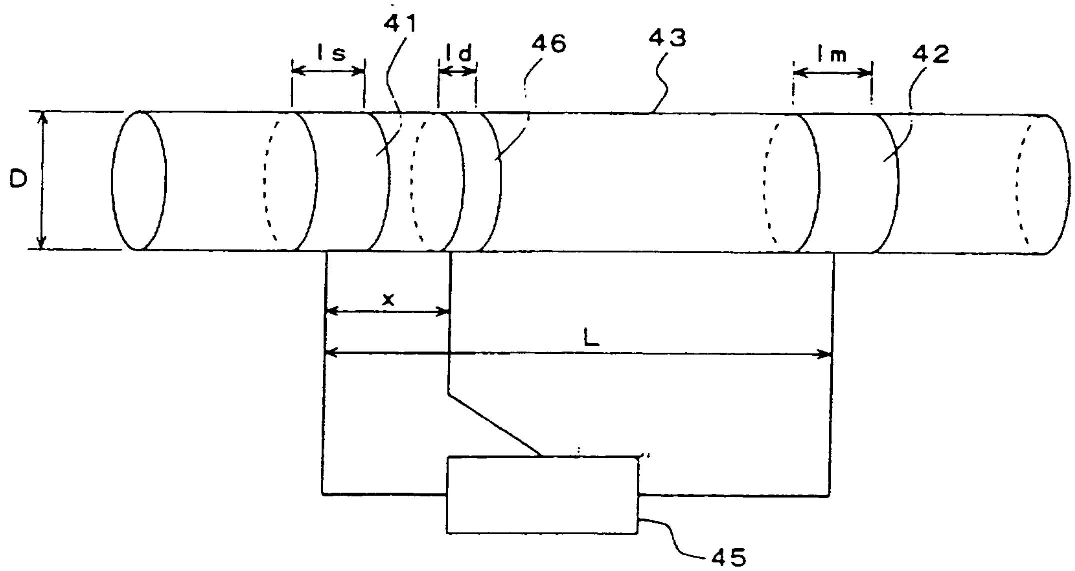


FIG. 6

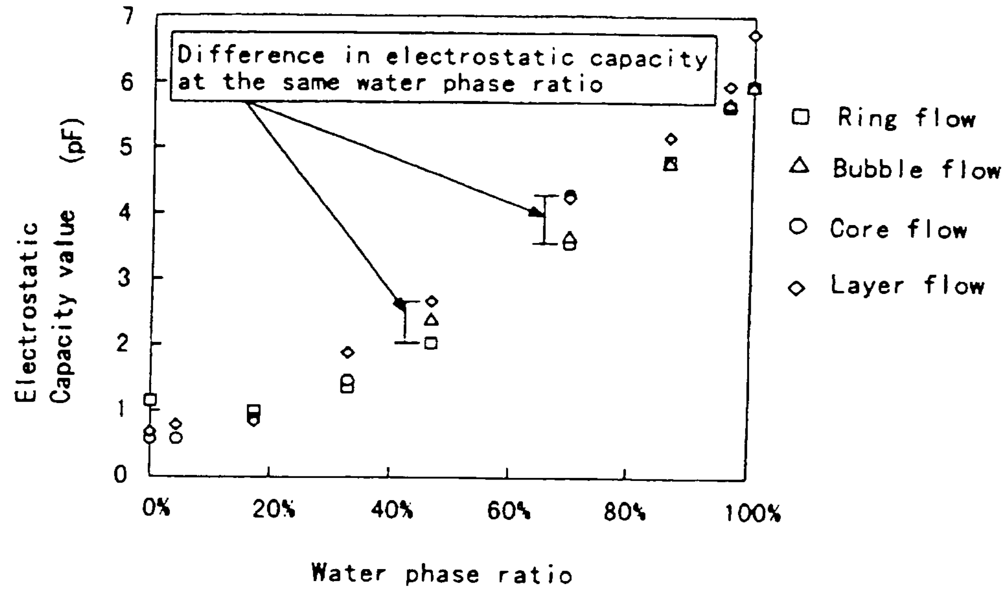
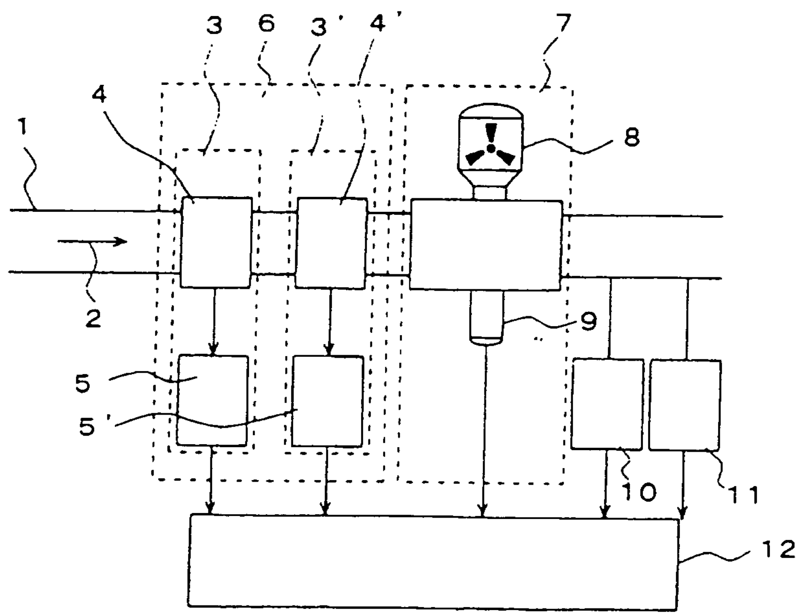

Difference in electrostatic capacity at the same water phase ratio
Electrostatic Capacity value (pF)
Water phase ratio
0%
20%
40%
60%
80%
100%
0
1
2
3
4
5
6
7
Ring flow
Bubble flow
Core flow
Layer flow

FIG. 7


1
2
3
4
5
5'
6
3'
4'
7
8
9
10
11
12

# 2330660

METHOD OF AND METER FOR MEASURING FLOW RATES OF CONSTITUENTS OF A MULTIPHASE FLUID

The present invention relates to an apparatus for on-line measurement of flow rates of constituents of a multiphase fluid, for example oil, water, gas,etc flowing in a pipe, without separating the respective fluids.

Conventionally, a flow meter for a multiphase flow composed of three or more sensors such as a water cut meter utilizing a difference in electrical properties among fluids, a density meter utilizing differences in density among fluids, and a flow meter measuring a total flow rate or a flow velocity of a multiphase fluid has been employed for measuring flow rates of constituent fluids constituting a multiphase fluid.

FIG. 7 is a block diagram of such a conventional flow meter for a multiphase flow. This flow meter has three sensors, that is, a cross-correlation flow meter 6 composed of two capacitance water cut meters 3 and 3' and a gamma-ray densitometer 7 for measuring an average density of a multiphase fluid 2.

The capacitance water cut meters 3 and 3' are composed of electrodes 4 and 4' and impedance measurement circuits 5 and 5' provided in a pipe 1. The gamma-ray densitometer 7 is composed of a source of gamma rays 8 and a detector 9.

An absolute pressure meter 10 and a thermometer 11 are used for temperature correction of parameters such as density and dielectric constant of each respective fluid and gas volumetric flow rate.

Now, a principle of measurement for the conventional apparatus is described.

An electrostatic capacity C of a multiphase fluid 2, which consists of oil, water and gas and flows in a pipe 1, is measured with a capacitance water cut meter 3. A transmittance $\lambda$ for gamma rays of the multiphase fluid 2 is measured with a gamma-ray densitometer 7. In the equation:

$$H_P + H_W + H_G = 1 \tag{1}$$

$H_P$ represents an oil phase ratio, $H_W$ represents a water phase ratio, and $H_G$ represents a gas phase ratio for the multiphase fluid 2 .

When known relative dielectric constants of oil, water, and gas are expressed by $\epsilon_P$, $\epsilon_W$, and $\epsilon_G$ :

$$\epsilon_P H_P + \epsilon_W H_W + \epsilon_G H_G = f_\epsilon(C) \tag{2}$$

establishes the relationship between the known relative dielectric constants and the electrostatic capacity C as measured.

When known densities of oil, water, and gas are expressed by $\rho_P$, $\rho_W$, and $\rho_G$ :

$$\rho_P H_P + \rho_W H_W + \rho_G H_G = f_\rho(\lambda) \tag{3}$$

establishes the relationship between the known densities and the gamma-ray transmittance $\lambda$ as measured.

Then, $f_\epsilon(C)$ and $f_\rho(\lambda)$ are intrinsic functions of the capacitance water cut meter 3 and the gamma-ray densitometer 7, and provide an average dielectric constant of the multiphase fluid 2 from an electrostatic capacity C and an average density of the multiphase fluid 2 from the transmittance $\lambda$, respectively.

On the other hand, a cross-correlation flow meter 6 composed of two capacitance water cut meters 3 and 3' measures a travel speed of fluctuations of electrostatic capacity C, that is, an average flow velocity u of the multiphase fluid 2.

An arithmetic circuit to calculate flow rates of the respective phases 12 alculates an oil phase ratio $H_P$, a water phase ratio $H_W$, and a gas phase ratio $H_G$ for the multiphase fluid 2 from the simultaneous equations (1)-(3) and then calculates flow rates of the respective fluids $Q_P$, $Q_W$, and $Q_G$ from Equations (4-1), (4-2), and (4-3) using a cross section A of the pipe 1 and the average flow velocity u.

$$Q_P = H_P \cdot A \cdot u \tag{4-1}$$

$$Q_W = H_W \cdot A \cdot u \tag{4-2}$$

$$Q_G = H_G \cdot A \cdot u \tag{4-3}$$

A method of obtaining a flow velocity from fluctuations of a multiphase fluid is described in detail in Japanese Patent Application No. 8-128389.

However, such a conventional apparatus requires a combination of at least three sensors such as two capacitance water cut meters and a gamma-ray densitometer to obtain component ratios and average flow velocities of respective fluids constituting a multiphase fluid. This limits simplification and size-reduction of flow meters for a multiphase flow.

In addition, since an average flow velocity u is solely used to calculate flow rates, there has been the problem that errors in flow rates of respective fluids measured become larger when a velocity slip (difference in velocity) exists between gas and liquid.

It is an object of the present invention to provide a flow meter for a multiphase flow composed of a smaller number of sensors than the conventional apparatuses and to provide a flow meter for a multiphase flow enabling highly accurate measurement in spite of velocity slip between gas and liquid.

The present invention is defined in the accompanying independent claims. Some preferred features are recited in the claims respectively dependent thereon.

According to one form of the method of the present invention, there is provided a cross-correlation flow meter for measuring basic values to calculate component ratios of respective fluids constituting a multiphase fluid comprising a gas and a plurality of liquids is provided to obtain the component ratios of the respective fluids on the basis of the measured values of the cross-correlation flow meter; when there is no velocity slip between a gas phase and a liquid phase in the multiphase fluid, an average flow velocity of the multiphase fluid is obtained on the basis of time differences in fluctuations of the measured values of the cross-correlation flow meter and then flow rates of the respective fluids are obtained by utilizing the respective component ratios and the average flow velocity; and when there is a velocity slip between the gas and liquid phases, a flow velocity of the gas phase of the multiphase fluid is obtained on the basis of the time between fluctuations (ie. the period between prescribed features in fluctuations, eg. the peak to peak period) of the measured values of the cross-correlation flow meter, and a sensor for measuring basic values to calculate a flow velocity of the liquid phase of the multiphase fluid is provided to obtain the flow velocity of the liquid phase on the basis of the measured values of the sensor, and then the flow rates of the respective fluids are calculated by utilizing the component ratio of a fluid in gas phase, the flow velocity of the gas phase, the component ratios of fluids in the liquid phase and the flow velocity of the liquid phase.

The cross-correlation flow meter may comprise two component ratio meters for measuring predetermined electrical values in a pipe through which the multiphase fluid flows, and the component ratios of the respective fluids are

otained by acquiring information concerning component ratios of the fluids in the liquid phase components from both measured values obtained by the component ratio meters at an instance when the pipe is filled with liquid alone during the passage of the multiphase fluid through the pipe and electrical characteristic values of the respective fluids, acquiring information concerning the component ratios of the respective fluids from both a time average of the measured values obtained by the component ratio meters and the respective electrical characteristic values, and utilizing the fact that a sum of the component ratios of the respective fluids becomes 1.

The cross-correlation flow meter may comprise two radiation densitometers for measuring radiation transmittance in a pipe through which the multiphase fluid flows, and the component ratios of the respective fluids are obtained by acquiring information concerning component ratios of the fluids in the liquid phase from both measured values obtained by the radiation densitometers at an instance when the pipe is filled with liquid alone during the passage of the multiphase fluid through the pipe and densities of the respective fluids, acquiring information concerning component ratios of the respective fluids from both a time average of the measured values obtained by the radiation densitometers and the respective densities, and utilizing the fact that a sum of the component ratios of the respective fluids becomes 1.

A differential pressure of the multiphase fluid is measured with a differential pressure type flow meter and a flow velocity of the liquid phase is obtained on the basis of the measured differential pressure, an average density of the multiphase fluid, and an intrinsic coefficient for the differential pressure type flow meter.

In one form the apparatus of the present invention comprises
a cross-correlation flow

meter provided in a pipe through which a multiphase fluids comprising a gas and lurality of liquids, for measuring basic values to calculate component ratios of respective fluids constituting the multiphase fluid; and an arithmetic circuit for calculating flow rates of the respective fluids, by acquiring information concerning component ratios of fluids in a liquid phase of the multiphase fluid from both measured values obtained by the cross-correlation flow meter at an instance when the pipe is filled with liquid alone during the passage of the multiphase fluid through the pipe provided with the cross-correlation flow meter and characteristic values of the respective fluids of the multiphase fluid, acquiring information concerning the component ratios of the respective fluids from both a time average of the measured values obtained by the cross-correlation flow meter and the respective characteristic values, obtaining the component ratios of the respective fluids by utilizing the fact that a sum of the component ratios of the respective fluids becomes 1, calculating an average flow velocity of the multiphase fluid on the basis of the period of fluctuations of the measured values obtained by the cross-correlation flow meter, and utilizing the respective component ratios and the average flow velocity for the calculation of the flow rates.

The apparatus of the present invention may comprise a sensor provided in a pipe, for measuring basic values to calculate a flow velocity of a liquid phase of a multiphase fluid; and the arithmetic circuit for calculating flow rates of the respective fluids with an additional function to calculate a flow velocity of a gas phase of the multiphase fluid on the basis of the time between fluctuations of the measured values of the cross-correlation flow meter when there is a velocity slip between a gas phase and a liquid phase of the multiphase fluids, to calculate a flow velocity of the liquid phase on the basis of the measured values obtained by the sensor, and to calculate flow rates of the respective fluids by utilizing the

component ratio and the flow velocity of the gas phase and the respective component and the flow velocity of the liquid phase.

In addition, the cross-correlation flow meter may comprise two component ratio meters for measuring an electrostatic capacity of the multiphase fluid and the characteristic values are in relative dielectric constant.

In addition, the cross-correlation flow meter may comprise two radiation densitometers for measuring radiation transmittance of a multiphase fluid and characteristic values are in density.

Each of the component ratio meters may comprise a cylindrical driving electrode for applying a voltage signal of predetermined amplitude and frequency to the multiphase fluid and a cylindrical measurement electrode virtually grounded for detecting a current flowing in through the multiphase fluid, both electrodes being arranged in parallel with the pipe through which the multiphase fluid flows, so as to measure a water phase ratio in the multiphase fluid by measuring an electrostatic capacity between the cylindrical driving electrode and the cylindrical measurement electrode, wherein a cylindrical dummy electrode with a potential identical to that of the cylindrical measurement electrode is placed between the cylindrical driving electrode and the cylindrical measurement electrode so as to reduce a part of an electric line of force toward the cylindrical measurement electrode through the vicinity of the wall of the pipe.

When an inner diameter of the pipe and inner diameters of the respective cylindrical electrodes are expressed by D, the widths of the cylindrical driving electrode, the cylindrical measurement electrode, and the cylindrical dummy electrode are expressed by $l_s$, $l_m$, and $l_d$, respectively, a distance between the cylindrical driving electrode and the cylindrical measurement electrode is

expressed by L, and a distance between the cylindrical driving electrode and the cylindrical dummy electrode may be expressed by x, in a preferred form in which:

$l_s/D = 0.3\text{-}1.0$

$l_m/D = 0.3\text{-}1.0$

$l_d/D = 0.1\text{-}0.5$

$L/D = 1.0\text{-}2.0$

$x/D = 0.4\text{-}1.2.$

The present invention provides a flow meter for a multiphase flow with a smaller number of sensors than conventional ones and thus enables simplification and size-reduction. In addition, even when there is a velocity slip between gas and liquid, highly accurate measurement of flow rates of the respective phases can be achieved by only adding a sensor. Furthermore, the accuracy of measurement of flow rate is enhanced through improvement of a component fraction meter.

The invention can be put into practice in various ways some of which will now be described with reference to the accompanying drawings, in which:

FIG. 1 is a block diagram of a flow meter for a multiphase flow according to one embodiment;

FIG. 2 is a flow pattern of a multiphase fluid in a pipe;

FIG. 3 shows a time-series waveform showing the output values of a capacitance water cut meter;

FIG. 4 is a block diagram of a flow meter for a multiphase flow according to Embodiment 2;

FIG. 5 is a block diagram of a capacitance water cut meter utilizing parallel cylindrical electrodes;

FIG. 6 shows the relationship between a water phase ratio and an electrostatic capacity value measured by the capacitance water cut meter of FIG. 5; and

FIG. 7 is a block diagram of a conventional flow meter for a multiphase flow.

## Embodiment 1

FIG. 1 is a block diagram of a flow meter for a multiphase flow.

A cross-correlation flow meter 26 is composed of two capacitance water cut meters 23 and 23', which comprise electrodes 24 and 24' provided in a pipe 1 and impedance measurement circuits 25 and 25' receiving the outputs from the electrodes 24 and 24' to measure an electrostatic capacity C of a fluid flowing through the pipe 1. The impedance measurement circuits 25 and 25' may be those measuring impedance at one frequency, that is, those possessing a source of alternating voltage at a given frequency.

A multiphase fluid comprising a gas and a plurality of liquids flows, in most cases, in a flow pattern with large bubbles 33 such as a slug flow and a plug flow through the pipe 1, as shown in FIG. 2. In FIG. 2, 32 denotes a liquid phase consisting of oil and water. FIG. 3 shows a time-series waveform of electrostatic capacity C measured by the capacitance water cut meter 23 at the time when the multiphase fluid flows in this pattern. The time-series waveform of electrostatic capacity C exhibits a vibrational waveform. The electrostatic capacity C becomes smaller when a large bubble 33 is passing through the electrode 24 and it becomes the maximum 37 when the large bubble 33 has passed the electrode 24 and only a liquid phase 32 exists. A ratio between oil and water is not

changed before, while, or after a large bubble 33 passes through.

When an oil phase ratio, a water phase ratio, and a gas phase ratio of a multiphase fluid 2 consisting of gas, water, and oil are expressed by $H_P$, $H_W$, and $H_G$, respectively, Equation (5) is established:

$$H_P + H_W + H_G = 1 \tag{5}$$

When known relative dielectric constants of the oil, water, and gas are expressed by $\epsilon_P$, $\epsilon_W$, and $\epsilon_G$, Equation (6):

$$\epsilon_P H_P + \epsilon_W H_W + \epsilon_G H_G = f_\epsilon (C_{mean}) \tag{6}$$

is established for the relationship between relative dielectric constant and a mean $C_{mean}$ of the electrostatic capacities C measured by the capacitance water cut meter 23.

For the maximum $C_{max}$ of electrostatic capacity C, on the other hand, since relative dielectric constants of oil and water only should be considered, Equation 7:

$$\epsilon_P H_P + \epsilon_W H_W = (1 - H_G) \cdot f_\epsilon (C_{max}) \tag{7}$$

is established.

Then, $f_\epsilon (C_{mean})$ and $f_\epsilon (C_{max})$ are intrinsic functions of the capacitance water cut meter 23, and provide an average dielectric constant of the multiphase fluid 2 from the electrostatic capacity $C_{mean}$ and the maximum dielectric constant of the multiphase fluid 2 from the electrostatic capacity $C_{max}$.

An average flow velocity u of the multiphase fluid 2 is measured from time differences in fluctuations of electrostatic capacity C which can be detected as a result of constituting the cross-correlation flow meter 26 with two capacitance water cut meters 23 and 23'.

An arithmetic circuit to calculate flow rates of the respective phases 22 calculates an oil phase ratio $H_P$, a water phase ratio $H_W$, and a gas phase ratio $H_G$

for a multiphase fluid 2 from the simultaneous equations (5)-(7) and then calculates flow rates of the respective fluids $Q_P$, $Q_W$, and $Q_G$ from Equations (4-1), (4-2), and (4-3) using a cross section A of the pipe 1 and the average flow velocity u.

The arithmetic circuit to calculate flow rates of the respective phases 22 can incorporate measurements from an absolute pressure meter 10 and a thermometer 11, as conventionally, to perform temperature correction of parameters such as density and dielectric constant of the respective fluids and (volume) flow rate of gas.

Embodiment 2

Now, a flow meter for a multiphase flow, which is effective when there is a velocity slip (difference in flow velocity) between gas and liquid of a multiphase fluid, is described. FIG. 4 shows a block diagram of the flow meter in which a differential pressure type flow meter 27 is added to the configuration of FIG. 1. Capacitance water cut meters 23 and 23' may have an alternating voltage signal source at a frequency, as in Embodiment 1. The differential pressure type flow meter 27 is provided with a differential pressure gauge 28.

Since multiphase fluid flow, in most cases, has a flow pattern with large bubbles called a slug flow or a plug flow, regardless of the presence of any velocity slip between gas and liquid, component fractions of the respective fluids contained can be calculated according to a principle similar to that used in Embodiment 1. That is, when a multiphase fluid 2 consists of gas, water, and oil, an oil phase ratio $H_P$, a water phase ratio $H_W$, and a gas phase ratio $H_G$ can be measured using only a capacitance water cut meter 23. In addition, since fluctuations of electrostatic capacity C, detected by a cross-

correlation flow meter having two capacitance water cut meters 23 and 23', are caused by travel of large bubbles, the speed of the large bubbles, ie. the gas phase velocity $u_G$ of the multiphase fluid 2, can be measured by timing the fluctuations.

On the other hand, when a velocity slip s between gas and liquid (=gas phase velocity $u_G$/liquid phase flow velocity $u_L$) is considered, a relationship between known densities of oil, water, and gas, $\rho_P$, $\rho_W$, and $\rho_G$, and an average density of the multiphase fluid 2, $\rho_M$, can be expressed by:

$$\rho_M = f_P(H_P, H_W, H_G, s) \cdot \rho_P + f_W(H_P, H_W, H_G, s) \cdot \rho_W + f_G(H_P, H_W, H_G, s) \cdot \rho_G \qquad (8)$$

wherein, $f_P$, $f_W$, and $f_G$ are weighted coefficients of density of the respective fluids provided by a function of $H_P$, $H_W$, $H_G$, and s.

A relationship between a differential pressure $\Delta p_V$ detected with a differential pressure type flow meter 27 and a liquid phase flow velocity $u_L$ of a multiphase fluid 2 can be expressed by:

$$u_L = \sqrt{\frac{\Delta P_V}{C_V \cdot \rho_M}} \qquad (9)$$

wherein $C_V$ is an intrinsic flow rate coefficient of the differential pressure type flow meter 27.

An arithmetic circuit 29 for calculating flow rates of the respective phases computes the respective component fractions, Hp, Hw and Hg, using Equations (5)-(7) and the liquid phase flow velocity $u_L$ by solving the simultaneous Equations (8) and (9).

In addition, the arithmetic circuit 29 calculates flow rates of the respective fluids of the multiphase fluid 2, $Q_P$, $Q_W$, and $Q_G$, by Equations (10-1), (10-2), and (10-3) using the component ratios $H_P$, $H_W$, and $H_G$ based on the measurements obtained by the capacitance water cut meter 23, the gas phase velocity $u_G$ based on the measurements obtained by the cross-correlation flow meter 26, and the liquid phase velocity $u_L$ based on the measurement by the differential pressure type flow meter 27:

$$Q_P = H_P \cdot A \cdot u_L \qquad (10\text{-}1)$$

$$Q_W = H_W \cdot A \cdot u_L \qquad (10\text{-}2)$$

$$Q_G = H_G \cdot A \cdot u_G \qquad (10\text{-}3)$$

The cross-correlation flow meter can include two microwave water cut meters or two gamma-ray densitometers, instead of the capacitance water cut meters 23 and 23'. Component fractions of the respective fluids of a multiphase fluid are obtained in a similar way.

Component ratios of the respective fluids of a multiphase fluid may be obtained, in a similar way, by using electrical characteristic values such as conductivity and magnetic permeability instead of relative dielectric constants.

As shown by the above respective embodiments, component ratios of a multiphase fluid, for example an oil-water-gas mixture, can be measured by using only conventional sensors for measuring component fractions of a two-phase fluid consisting of gas and water, such as a water cut meter and a gamma-ray densitometer. Thus, the size and component count of such a meter can be reduced.

In addition, because it is sufficient to provide only one measurement condition, measurement can be simplified. For example, when electrostatic

capacity is measured, it is sufficient to conduct measurement at one frequency. When microwave and gamma rays are used, it is sufficient to perform measurement at one wavelength.

In addition, even when there is a velocity slip between gas and liquid, the addition of one sensor enables measurement of flow rates of respective phases with high accuracy.

Finally, a constitution of a capacitance water cut meter which further increases accuracy of the flow meter for a multiphase flow of the present invention is described.

FIG. 5 is a block diagram of a capacitance water cut meter. A cylindrical dummy electrode 46 with an axial thickness of ld is arranged in the pipe 43 between a cylindrical driving electrode 41 and a cylindrical measurement electrode 42. A capacitance or impedance measurement circuit 45 receives the outputs from electrodes 41, 42 and 46. Both of the electrodes are arranged apart from each other in the pipe 43 through which the multiphase fluid flows, such that the measurement by the circuit 45 provides a water phase ratio based on the electrostatic capacity. In other words, between the cylindrical driving and measurement electrode 41 and 42 the alternating voltage signal is applied at a specific amplitude and frequency. The measurement electrode 42 is virtually grounded (if not actually grounded) to detect electrical current flow in through the fluid. The dummy electrode 46, applied with a potential identical to that of the cylindrical measurement electrode 42, is positioned to measure the electrostatic capacity between the cylindrical driving electrode 41 and the cylindrical measurement electrode 42, while absorbing and reducing a part of an electric line of force toward the cylindrical measurement electrode 42 though the vicinity of the wall of the pipe 43.

When the inner diameter of the pipe 43 and the inner diameters of the respective cylindrical electrodes are expressed by D, the thicknesses of the cylindrical driving electrode 41, the cylindrical measurement electrode 42, and the cylindrical dummy electrode 46 are expressed by Is, Im, and Id, respectively, the distance between the cylindrical driving electrode 41 and the cylindrical measurement electrode 42 is expressed by L, and the distance between the cylindrical driving electrode 41 and the cylindrical dummy electrode 46 is expressed by x, in the water cut meter:

$l_s/D = 0.3\text{-}1.0$

$l_m/D = 0.3\text{-}1.0$

$l_d/D = 0.1\text{-}0.5$

$L/D = 1.0\text{-}2.0$

$x/D = 0.4\text{-}1.2$

Preferably, $l_d/D = 0.1\text{-}0.2$ and $x/D = 0.4\text{-}0.8$.

Using the capacitance water cut meter shown in FIG. 5, an experiment using water and a plastic bar simulating several representative flow patterns was conducted. The results of measurement of the distribution of electrostatic capacity against a water phase ratio of the fluid are shown in FIG. 6, wherein

$l_s/D = 0.36$, $l_m/D = 0.36$, $l_d/D = 0.18$, $L/D = 1.45$, and $x/D = 0.45$.

The results show that the dispersion of electrostatic capacity values due to differential flow of a multiphase fluid was greatly improved as compared with those in conventional flow meters at the same water phase ratio.

In other words, the water cut meter of the present invention can reduce dispersions of measured electrostatic capacity values due to differential flow patterns and can thereby provide a water phase ratio measurement of a multiphase fluid accurately without reference to the flow pattern.

## CLAIMS:

1. A method of measuring flow rates of respective fluids constituting a multiphase fluid using: a cross-correlation flow meter having a meter output for calculating component ratios of the respective fluids, comprising a gas and a plurality of liquids, to obtain the component ratios of the respective fluids on the basis of the meter output, and a sensor having a sensor output for deriving a flow velocity of the liquid phase in the multiphase fluid, the method comprising:

when there is no velocity slip between the gas phase and the liquid phase in the multiphase liquid, calculating an average flow velocity of the multiphase fluid on the basis of the time between fluctuations of the meter output of the cross-correlation flow meter; and

calculating the flow rates of the respective fluids from the component ratios of the respective fluids and the average flow velocity; or

when there is a velocity slip between the gas and liquid phases, calculating a flow velocity of the gas phase of the multiphase fluid on the basis of the time between fluctuations in the meter output of the cross-correlation flow meter;

deriving the flow velocity of the liquid phase from the sensor output of the sensor; and

calculating the flow rates of the respective fluids from the component ratio of the fluid in the gas phase, the flow velocity of the gas phase, the component ratios of the fluids in the liquid phase and the flow velocity of the liquid phase.

2. A method according to claim 1 wherein the cross-correlation flow meter

comprises two component ratio meters, providing ratio meter outputs indicative of predetermined electrical parameters, in a conduit through which the multiphase fluid flows;

and the component ratios of the respective fluids are obtained by deriving information concerning the component ratios of the fluids in the liquid phase from both ratio meter outputs when the conduit bears liquid alone during the passage of the multiphase fluid through the pipe and values of the electrical parameters of said respective fluids, deriving information concerning the component ratios of the respective fluids from both a time average of the ratio meter outputs from the component ratio meters and the respective values of the electrical parameters and a summation of the component ratios of the respective fluids to 1. .

3. A method according to claim 1 wherein the cross-correlation flow meter comprises two radiation densitometers, providing densitometer outputs indicative of radiation transmittance, in a conduit through which the multiphase fluid flows;

and the component ratios of the respective fluids are obtained by deriving information concerning the component ratios of the fluids in the liquid phase from both densitometer outputs when the conduit bears liquid alone during the passage of the multiphase fluid through the pipe and densities of the respective fluids, deriving information concerning the component ratios of the respective fluids from both a time average of the densitometer outputs from the radiation densitometers and the respective densities, and a summation of the component ratios of the respective fluids to 1.

4. A method according to claim 1 wherein a differential pressure of the multiphase fluid is measured with a differential pressure type flow meter and the flow velocity of the liquid phase is derived from the measured differential pressure, an average density of the multiphase fluid, and an intrinsic coefficient for the differential pressure type flow meter.

5. A flow meter for determining the flow rates of fluids in a multiphase flow comprising a gas and a plurality of liquids, the meter comprising:

a cross-correlation flow meter arranged in operative relation to a conduit bearing the multiphase fluid and having a meter output;

computing means for calculating the flow rates, the computing means being arranged to receive the meter output and being operable to derive information related to the component ratios of the liquid phase, when only liquids are present in the conduit, from the meter outputs and characteristic values of the respective liquids of the multiphase flow, being operable to derive information related to the component ratios for the multiphase fluid from a time average of the meter output and the characteristic values of the respective fluids in the multiphase flow, and being operable to determine the component ratios of the respective fluids from a summation of the component ratios to 1, the computer means further being operable to calculate an average flow velocity of the multiphase fluid from the time between fluctuations of the meter output and to derive the flow rates of the respective fluids from the component ratios and the average flow velocity.

6. A flow meter for a multiphase flow according to claim 5 including a sensor provided in the conduit to provide the meter output;

and the computing means are further operable to calculate a flow

velocity of a gas phase of the multiphase fluid on the basis of the time between fluctuations of the meter output to calculate a flow velocity of a liquid phase on the basis of the meter output, and to calculate flow rates of the respective fluids by utilizing a component ratio of a fluid in said gas phase, the flow velocity of said gas phase, respective component ratios of fluids in the liquid phase and the flow velocity of said liquid phase, in the event of velocity slip between the gas and liquid phases.

7. A flow meter for a multiphase flow according to claim 5 wherein the cross-correlation flow meter comprises two component ratio meters for measuring an electrostatic capacitance of the multiphase fluid and the characteristic values are the dielectric constants of the fluids.

8. A flow meter for a multiphase flow according to claim 5 wherein said cross-correlation flow meter comprises two radiation densitometers for measuring radiation transmittance of the multiphase fluid and the characteristic values are in the densities of the fluids.

9. A flow meter for a multiphase flow according to claim 7 wherein each of the component ratio meters comprises a cylindrical driving electrode for applying a voltage signal of predetermined amplitude and frequency to the multiphase fluid and a grounded cylindrical measurement electrode for detecting a current flowing through the multiphase fluid, both electrodes being arranged in parallel in the conduit through which the multiphase fluid flows, so as to measure a liquid phase ratio in the multiphase fluid by measuring the electrostatic capacitance between the cylindrical driving electrode and the cylindrical measurement electrode, and a further cylindrical dummy electrode

with a potential substantially identical to that of the cylindrical measurement electrode placed between the cylindrical driving electrode and the cylindrical measurement electrode so as to reduce a part of an electric line of force toward the cylindrical measurement electrode through the vicinity of the wall of the pipe.

10. A flow meter for a multiphase flow according to claim 9 wherein when an inner diameter of the conduit and inner diameters of the respective cylindrical electrodes are expressed by D, the widths of the cylindrical driving electrode, the cylindrical measurement electrode, and the cylindrical dummy electrode are expressed by Is, Im and Id, respectively, the distance between the cylindrical driving electrode and the cylindrical measurement electrode is expressed by L, and the distance between the cylindrical driving electrode and the cylindrical dummy electrode is expressed by x, and in which:

Is/D = 0.3-1.0

Im/D = 0.3-1.0

Id/D = 0.1-0.5

L/D = 1.0-2.0

X/d = 0.4-1.2

# The Patent Office

21

**Application No:** GB 9822944.6
**Claims searched:** 1 to 10

**Examiner:** A J Oldershaw
**Date of search:** 23 December 1998

## Patents Act 1977
## Search Report under Section 17

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): G1N CVT; G1A BAA, BAG

Int Cl (Ed.6): G01F

Other: Online: WPI

**Documents considered to be relevant:**

| Category | Identity of document and relevant passage | | Relevant to claims |
|---|---|---|---|
| A | GB2219396A | (COMMONWEALTH SCIENTIFIC) | |
| A | GB2106645A | (BRENNSTOFFINSTITUT) | |
| A | EP0510774A2 | (SHELL INTERNATIONALE) | |
| X | WO93/24811A1 | (COMMONWEALTH SCIENTIFIC) | 5 at least |

X Document indicating lack of novelty or inventive step
Y Document indicating lack of inventive step if combined with one or more other documents of same category.
& Member of the same patent family
A Document indicating technological background and/or state of the art.
P Document published on or after the declared priority date but before the filing date of this invention.
E Patent document published on or after, but with priority date earlier than, the filing date of this application.